National Exams - December 2018

16-Elec-B2, Advanced Control Systems

3 hours duration

NOTES:

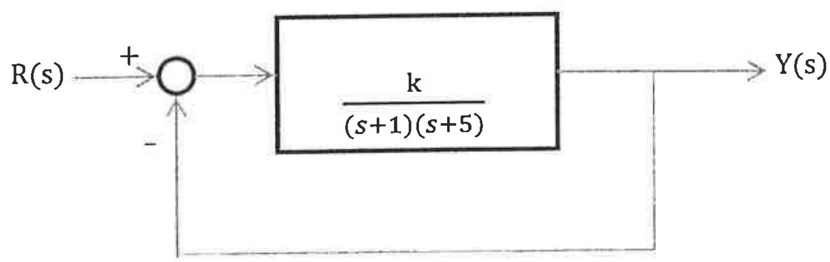
1. This is an open book exam.
2. If a doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
3. Candidates may use any non-communicating calculator. Tables of Laplace are attached.
4. Any four questions constitute a complete paper. Only the first four questions as they appear in your answer book will be marked.
5. All questions are of equal value (25%). (Exam notebook contains 20 pages)

Question 1. Choose the best answer.

a. What is the type of the system when the steady-state error of a feedback control system with an acceleration (parabola) input becomes finite? **[1]**

(a) Type 0 system
(b) Type 1 system
(c) Type 2 system
(d) Type 3 system

b. For the system shown below, what is the value of the k that yields a stable system with critically damped response? **[2]**



(a) k = 2
(b) k = 4
(c) k = 8
(d) k = 16

c. In a system with complex poles, the real part of a pole generates what part of the system response? **[1]**
(a) Time constant of an exponential response
(b) Amplitude of a sinusoidal response
(c) Radian frequency of a sinusoidal response
(d) None of the above

d. What is the rise time of the following system? **[1]**

$$T(s) = \frac{16}{s^2 + 3s + 16}$$

(a) 0.356 sec
(b) 2.33 sec
(c) 7.5 sec
(d) None of the above

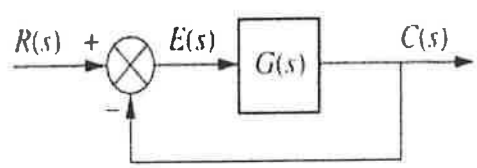
e. Determine the location of the poles for the system represented by the following Routh table? [2]

s^5	1	4	3
s^4	-1	-4	-2
s^3	ε	1	0
s^2	$\frac{1-4\varepsilon}{\varepsilon}$	-2	0
s^1	$\frac{2\varepsilon^2+1-4\varepsilon}{1-4\varepsilon}$	0	0
s^0	-2	0	0

(a) 2 rhp, 3 lhp
(b) 3 rhp, 2 lhp
(c) 2 rhp, 2 lhp, 1 on $j\omega$
(d) 2 rhp, 1lhp, 2 on $j\omega$

f. Calculate closed loop transfer function of the unity feedback with

$$G(s) = \frac{K(s+6)}{s(s+1)(s+4)}$$

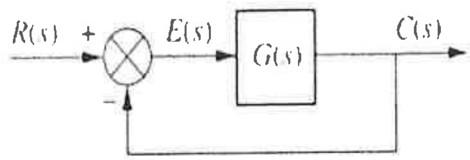


Without forming the Routh table, can you find the range of K for stability of the following system? [2]

(a) K>-2
(b) 0< K <1
(c) K> -1
(d) 1 < K < 2

g. What is the value of K for the unity feedback system shown where

$$G(s) = \frac{K(s+3)}{s^2(s+7)}$$



if the input is $10t^2u(t)$, and the desired steady-state error is 0.061 for this input? **[2]**

(a) 521.02
(b) 334.14
(c) 512.11
(d) 765.03
(e) None of the above

h. If the zero of a feedback compensator is at – 3.0 and the close-loop system pole is at – 3.001, can you say that there will be pole-zero compensation? **[1]**

(a) Yes
(b) No

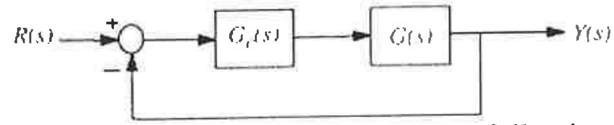
i. What are the total contributions of four poles to the Bode magnitude plot? **[1]**

(a) +20 dB/dec
(b) +80 dB/dec
(c) –20 dB/dec
(d) –80 dB/dec

j. If a pure time delay T is introduced to the system, how will the Bode magnitude plot will change? **[1]**

(a) A straight line with the slope of $+\omega T$
(b) A straight line with the slope of $-\omega T$
(c) A constant value of $20\log(T)$
(d) No change at all

k. Consider the feedback control system block diagram

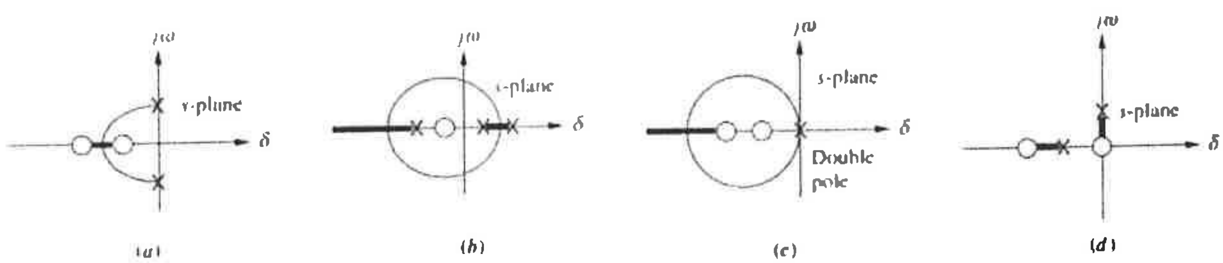


Which condition holds for the closed-loop stability with the following transfer functions? **[2]**

$$G_c(s) = K(s+1) \qquad \text{and} \qquad G(s) = \frac{1}{(s+2)(s-1)}.$$

(a) Unstable for $K = 1.10$ and unstable for $K = 3$
(b) Stable for $K = 1.10$ and stable for $K = 3$
(c) Unstable for $K = 1.10$ and stable for $K = 3$
(d) Stable for $K = 1.10$ and unstable for $K = 3$

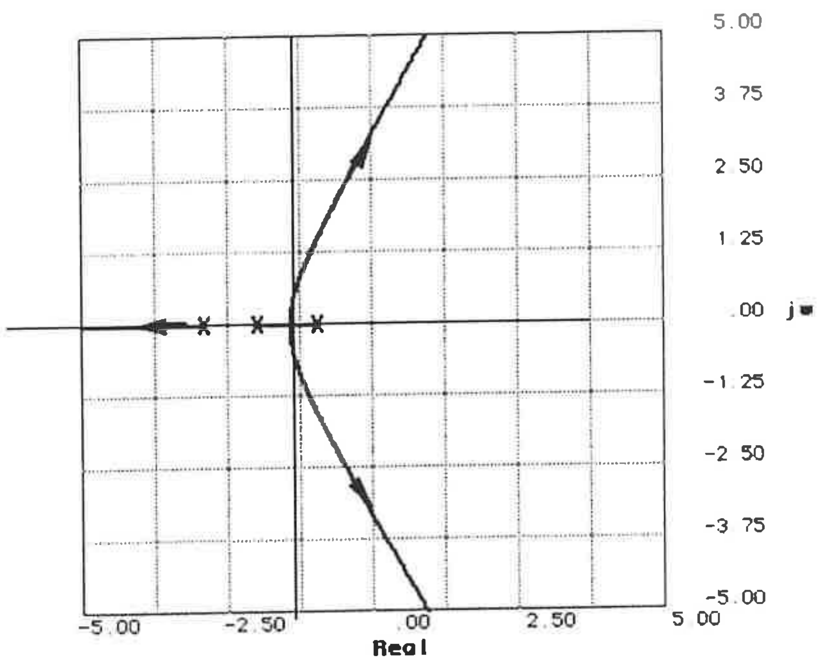
l. Which one of the following sketches can be a root locus? **[1]**



(a) a
(b) b
(c) c
(d) d

m. For the following root locus (with open loop poles at -1, -2 and -3), what are the coordinates of closed loop system poles for 20% overshoot? **[2]**

(a) $-1.25 \pm 0.8j$
(b) $-1 \pm 1.25j$
(c) $-0.86 \pm 1.69j$
(d) $-0.5 \pm 2.5j$



n. What is the gain (K) value corresponding to those poles providing 20% overshoot in the previous problem? **[2]**

(a) 6.342
(b) 9.398
(c) 7.301
(d) 3.221

o. What is the peak time (T_p) associated with those poles in the same problem? **[2]**

(a) 3.92
(b) 2.51
(c) 1.85
(d) 1.26

p. What is the settling time (T_s) associated with those poles in the same problem? **[1]**

(a) 3.2
(b) 4.0
(c) 4.6
(d) 8.0

q. Consider a forward path transfer function $G(s)$ with gain K. Which statements are true for this system? **[1]**

1) The zeros of the closed loop system change with changing gain K.

2) The poles of the closed loop system change with changing gain K.

(a) None of them is true
(b) Only 1 is true
(c) Only 2 is true
(d) Both are true

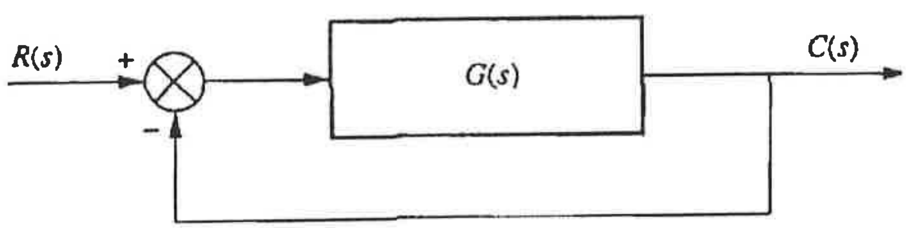
Question 2.

(**Part A**). A unity feedback control system has the following forward-path transfer function [**12**].

a) Find the angle of asymptotes.
b) Find the breakaway points' coordinates.

$$G(s) = \frac{K(s-0.5)}{(s-1)^2}$$

(**Part B**) For the unity feedback system below: ([**13**])



$$G(s) = \frac{K(s-1)(s-2)}{s(s+1)}$$

a) Determine closed loop transfer function first and then find the $j\omega$ -axis crossing coordinates and corresponding K value using Routh-Hurwitz table.
b) Knowing that the Breakaway point is at: -0.37 ($K = 0.07$) and the Break-in point is at: 1.37 ($K = 13.93$), plot approximate root locus of the system.

Question 3.

A unity feedback system with loop gain $G(s) = \dfrac{10}{s(s+10)(s+20)}$ is to be controlled with a PD controller. The desired poles of the system were calculated to be $s = -12.78 \pm j24.94$.

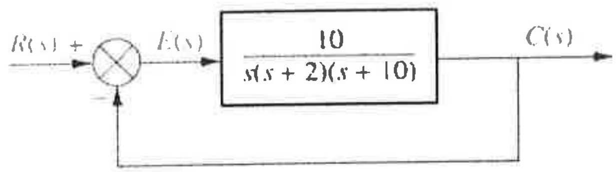
The goal is to find the location of the zero of the PD controller to achieve the desired poles (shown above).

a) Calculate the summation of the angles from the open loop poles to the design point.
b) Calculate the zero angle contribution.
c) Find the location of the zero for PD controller (do not need to calculate K value).

Question 4.

For the system shown in the following figure,

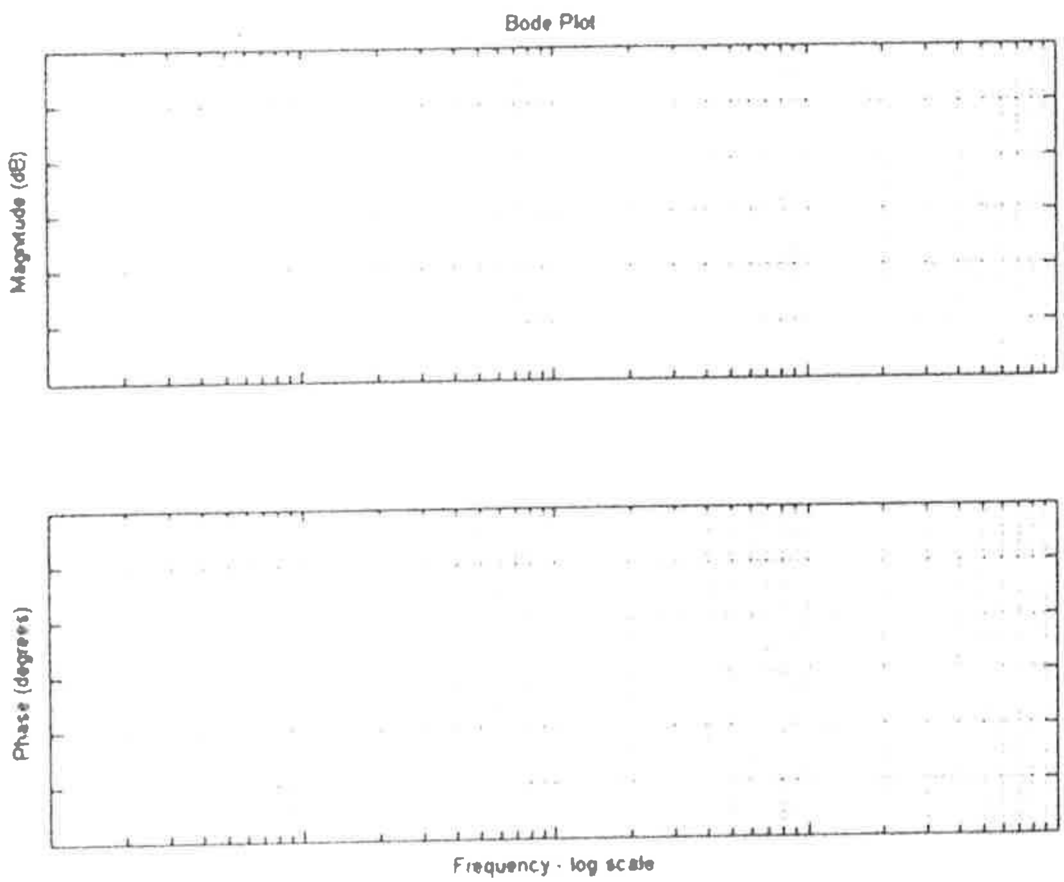
(a) Use the transfer function G(s) of the system to sketch the approximate Bode log-magnitude and phase plots for each component of the unity feedback system given the open-loop transfer function when $K = 20$:



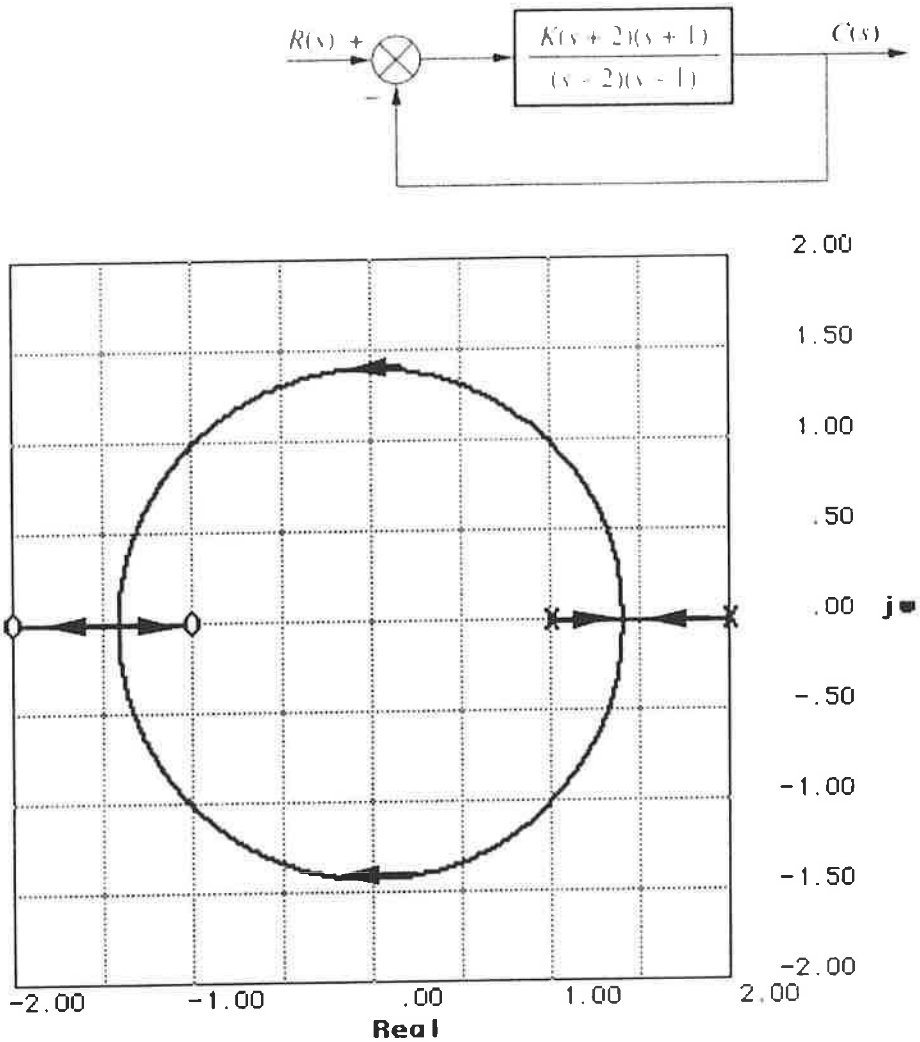
after normalizing the given transfer function. You need to sketch magnitude and phase plots for each component first (i.e., overall gain after nornmalization, and three poles). Then you need to show the overall Bode diagram.

(b) Find the gain margin, phase margin and their frequencies for the system when $K = 20$.

(c) What would be the maximum gain (K) to keep the system stable?



Question 5.
The root locus of a system is provided in the following figure.



(a) Find the location of closed-loop system poles (design poles) to provide $\zeta = 0.707$ (use the provided scaled graph to avoid numerical calculations).
(b) Find the value of K corresponding to the design poles.
(c) Find the value of settling time corresponding to the design poles.
(d) It is desired to make the system faster (by factor of 3, i.e., one third of the existing settling time) but to have the same damping ratio. What would be the new design poles location?
(e) Calculate the summation of the angles to the new design pole?
(f) An engineer claims to design a PD compensator to achieve the new design poles. Calculate the angle contribution of z_c of PD controller. Discuss in ONE line the validity of the claim.
(g) Design a PI controller to make steady state error diminish (choose zero location at 0.1).

Inverse Laplace Transforms	
$F(s)$	$f(t)$
$\dfrac{A}{s+\alpha}$	$Ae^{-\alpha t}$
$\dfrac{C+jD}{s+\alpha+j\beta}+\dfrac{C-jD}{s+\alpha-j\beta}$	$2e^{-\alpha t}\left(C\cos\beta t+D\sin\beta t\right)$
$\dfrac{A}{(s+\alpha)^{n+1}}$	$\dfrac{At^{n}e^{-\alpha t}}{n!}$
$\dfrac{C+jD}{(s+\alpha+j\beta)^{n+1}}+\dfrac{C-jD}{(s+\alpha-j\beta)^{n+1}}$	$\dfrac{2t^{n}e^{-\alpha t}}{n!}\left(C\cos\beta t+D\sin\beta t\right)$

Table of Laplace and z-Transforms (*h* denotes the sample period)		
$f(t)$	$F(s)$	$F(z)$
unit impulse	1	1
unit step	$\frac{1}{s}$	$\frac{hz}{z-1}$
$e^{-\alpha t}$	$\frac{1}{s+\alpha}$	$\frac{z}{z-e^{-\alpha h}}$
t	$\frac{1}{s^2}$	$\frac{hz}{(z-1)^2}$
$\cos \beta t$	$\frac{s}{s^2+\beta^2}$	$\frac{z(z-\cos \beta h)}{z^2-2z\cos \beta h+1}$
$\sin \beta t$	$\frac{\beta}{s^2+\beta^2}$	$\frac{z\sin \beta h}{z^2-2z\cos \beta h+1}$
$e^{-\alpha t}\cos \beta t$	$\frac{s+\alpha}{(s+\alpha)^2+\beta^2}$	$\frac{z\left(z-e^{-\alpha h}\cos \beta h\right)}{z^2-2ze^{-\alpha h}\cos \beta h+e^{-2\alpha h}}$
$e^{-\alpha t}\sin \beta t$	$\frac{\beta}{(s+\alpha)^2+\beta^2}$	$\frac{ze^{-\alpha h}\sin \beta h}{z^2-2ze^{-\alpha h}\cos \beta h+e^{-2\alpha h}}$
$t\,f(t)$	$-\frac{dF(s)}{ds}$	$-zh\frac{dF(z)}{dz}$
$e^{-\alpha t}f(t)$	$F(s+\alpha)$	$F(ze^{\alpha h})$